

A new concept for streamer quenching in resistive plate chambers

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Abstract

In this paper we propose a new concept for streamer quenching in Resistive Plate Chambers (RPCs). In our approach, the multiplication process is quenched by the appropriate design of a mechanical structure inserted between the two resistive electrodes. We show that stable performance is achieved with binary gas mixtures based on argon and a small fraction of isobutane. Fluorocarbons, deemed responsible for the degradation of the electrode inner surface of RPC detectors, are thus fully eliminated from the gas mixture. This design also resulted in a simplified assembly procedure. Preliminary results obtained with a few prototypes of “Mechanically Quenched RPCs” and some prospects for future developments are discussed.

Key words: RPC, Streamer mode, Freon-less, Mechanical quenching.

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1 Introduction

Resistive Plate Chambers (RPCs), gaseous detectors with parallel resistive plates [1,2], can provide both good spatial information and time resolution in detecting charged particles over large areas at low cost.

Besides the traditional use of RPCs as a low cost coarse tracker, to identify muons and provide an estimate of their momenta, new prospects for their applications as the active part of a digital hadron calorimeter at the International Linear Collider experiment [3] and for X- or gamma-source imaging [4] are emerging. These are spurring again the R&D program toward a reliable detector, suited for large scale application in modern experiments, where industrial standards for mass production with quality control and assurance and stable performance over the long term are compulsory.

RPCs can be operated in avalanche mode and in streamer mode. The former has an advantage in terms of a higher rate capability, while the latter carries an advantage in terms of larger signals (order of 100 pC). A typical gas mixture for RPC operated in streamer mode consists of argon (Ar), butane (C_4H_{10}) and a non-flammable fluorocarbon (freon). The ternary mixtures have been proved to provide stable operation with high efficiency to detect minimum ionising particles. Operations without freon have also been studied by many groups and various types of freon-less gas mixtures or mixtures with very low freon concentration have been reported [5,6,7,8,9,10]. An interesting alternative to freon is the use of SF_6 , which has a very high electron affinity and enables for reasonable streamer quenching at concentrations as small as 1% [11]. These attempts, however, never resulted in a large scale application of RPCs, where non-flammable and low cost gas mixtures are required. Thus, gas mixtures with a large fraction of an environmentally friendly freon, the tetrafluoroethane (CH_2FCF_3) known as HFC-134a, are commonly used [12,13]. It is however desirable not to use these gases in the future, as they are being recognised as the main source of RPC instability in the long term. Indeed, by decomposition of the tetrafluoroethane, under electrical discharges, hydrofluoric acid (HF) can be formed, which is a very aggressive one and is expected to have a main role in damaging the RPC inner surface [14]. In particular, the corrosive effect of HF in RPC detectors with glass electrodes is a fully fledged phenomenon [15,16]. HF acid has long been known in glass and silicon industry for its etching properties, indeed.

In this paper we propose a new concept for streamer quenching, based on a completely different approach. We argue that the role of the freon gas can be fully replaced by the appropriate design of a mechanical structure inserted between the two resistive electrodes. In practice this is achieved by introducing a honeycomb structure opaque to UV photons between the two resistive

electrodes to keep the streamer confined in one single cell. There are several technical problems that need to be addressed: the honeycomb material should be an excellent insulator; the cell dimensions must be tuned to the streamer area; the cell walls must be thin enough to avoid a geometrical loss of efficiency; a way to let the gas flow through the chamber need to be found. Yet a material almost ideal for this kind of application is commercially available.

In the following, after the description of the mechanical realisation of the first prototypes and of the experimental setup adopted for a preliminary characterisation of the detectors, we show that stable performance is achieved with binary gas mixes based on argon and a small fraction of isobutane.

2 Detector description and measurement setup

The basic element of our “Mechanically Quenched” RPCs is a ECA-I core honeycomb structure¹, made by an aramid fibre paper coated with phenolic resin. This material has a high strength-to-weight ratio, is electrically insulating, chemically, corrosion and flame resistant. Honeycomb sheets are available with hexagonal cell sizes from 3.2 mm to 19.2 mm diameter and minimum thickness of 2 mm. The cell walls are less than 50 μm thick for the lowest cell sizes, giving a geometric fill-factor, defined as the ratio of the potentially active area to the total area, in excess of 90% for 3.2 mm wide hexagonal cells. Moreover, a direct measurement of the light transmission through the aramid fibre paper have shown that the cell walls are opaque to UV photons up to 360 nm and transmit only about 10% of the visible light.

We constructed test RPCs $20 \times 20 \text{ cm}^2$ in size using resistive electrodes of 2 mm thick float glasses with $4 \times 10^{12} \Omega\text{cm}$ bulk resistivity at room temperature. One honeycomb foil 2 mm thick with 3.2 mm hexagonal cells was inserted between the electrodes. An external frame of polycarbonate, to which the glass electrodes were glued, guaranteed the gas tightness of the chamber (see Figure 1). This assembly procedure was simpler than for standard RPCs, as the honeycomb sheet guaranteed a constant gap between the electrodes with no need for specific spacers. Prototypes with 3 mm thick glasses were also built and tested, but the high bulk resistivity of the glass batch used for these chambers ($> 10^{13} \Omega\text{cm}$) resulted in poor performance. The high voltage was supplied to the outside surface of the glasses by a thin pre-coated paint (silk screen printed) covering an area of $18 \times 18 \text{ cm}^2$ with 200-400 $\text{k}\Omega/\square$ resistivity. The signal was readout on external pickup copper electrodes, covered with a PET sheet for electrical insulation from the chamber. In most of the measurements,

¹ ECA-I is a product name in the catalogue of Euro-Composites, Zone Industrielle, L-6401, Echternach, Luxembourg.

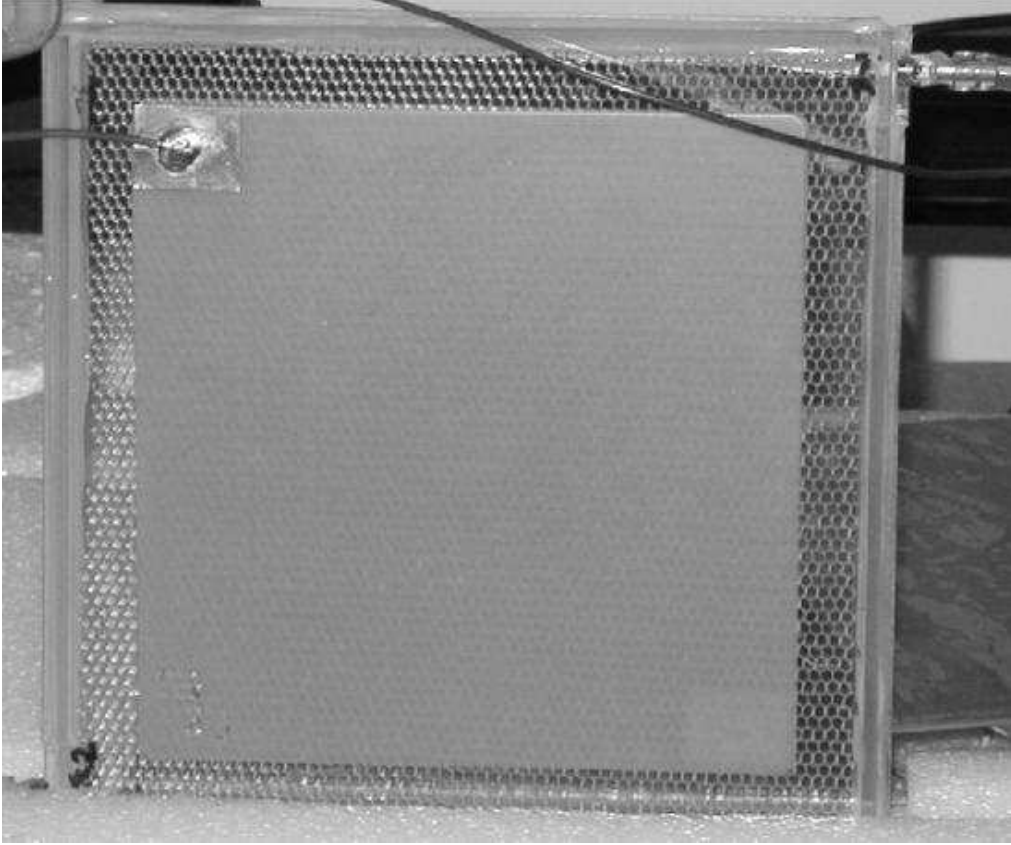


Fig. 1. One RPC prototype with the honeycomb structure inserted between the glass electrodes. The silk screen printed coating and the electrical contact for supplying the high voltage are visible.

one single copper readout pad, covering the entire detector surface was used, thus no position information was available. Both analog and digital readout of the signal was performed, to measure the streamer charge, the chamber noise (single count rate) and the time resolution. Digital information was obtained after signal discrimination with -30 mV threshold.

The performance of the RPC prototypes was tested with cosmic rays. The coincidence of two scintillators, placed above and below the chambers, provided a trigger over an area of about $8 \times 8 \text{ cm}^2$ around the chamber centre. At every trigger, the ADC (LeCroy 2249A) and TDC (LeCroy 2228A) information were readout, as well as the content of a scaler, which recorded the single rate and the three fold coincidences of each chamber with the two scintillators. For charge measurements, the ADC gate was set to 250 ns, well in excess of the pulse duration, and the pulses were attenuated by 12 dB at the ADC input to match the ADC dynamical range. The start to the TDC for time measurements was given by the bottom scintillator, with one stop for each RPC.

As the honeycomb structure was expected to play the role of HFC-134a in

confining the transverse dimensions of the streamer, the RPCs were tested with binary Ar/isobutane non-flammable mixtures. The isobutane concentration was varied from 2% to 8% by means of rotameters. The range of operations of the rotameters available for this test implied a relatively high gas flow rate of around 50 cc/min in total, corresponding to the change of one chamber volume every 2 min, approximately. The gas inlet and outlet were located on the external frame of the RPCs (see Fig. 1) and no special care was taken in the design of the chamber to ease the gas flow through the honeycomb. This might require further consideration in the future. It is an experimental fact that, at the flow rates used in these tests, there is enough room for the gas to flow between the inner surface of the electrodes and the honeycomb sheet².

3 Detector performance

A preliminary characterisation of the detector performance was accomplished by studying the detection efficiency to cosmic rays, the signal pulse shape and the time resolution. The results reported hereafter describe the performance of the two RPC prototypes assembled with 2 mm thick glass electrodes. After assembly, the RPC prototypes were fluxed, at the above mentioned rate, with an Ar/isobutane 97/3 mixture and conditioned at 5 kV for about one week, until stable efficiency and single count rate were achieved.

3.1 Efficiency and single count rate

The efficiency plateau and the single count rate curves of the RPC for several Ar/isobutane mixtures are shown in Fig. 2. The curves shift toward higher voltages when increasing the fraction of isobutane. At small isobutane fractions (<4%) the chamber was not efficient, as secondary streamers were not sufficiently quenched. In the limit of pure Ar, not reported in the figure, the chamber was completely inefficient, because of long after-pulses. Isobutane fractions larger than 4% enabled stable RPC operation, although with an inefficiency somewhat larger than expected from geometrical considerations. The best performance was observed with a 95/5 mixture, showing a plateau efficiency of about 80% for a supplied high voltage of about 6.5 kV. The efficiency loss may be due to several reasons that require further investigation. The extension of the inefficient area around the honeycomb has to be investigated in detail: the field quality there might be such that the efficiency loss region is wider than the aramid structure itself. Another source of inefficiency may

² The thickness tolerance of the honeycomb sheets is about 0.2 mm.

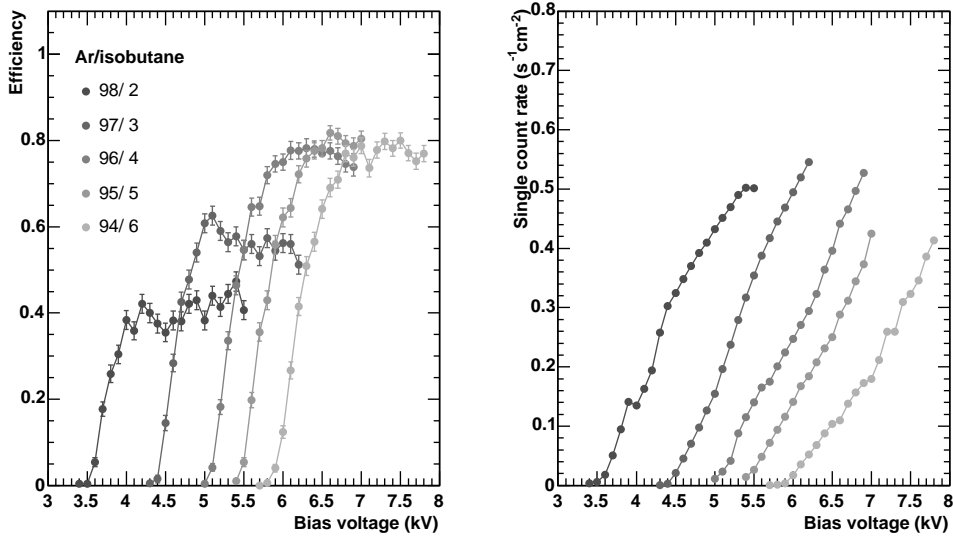


Fig. 2. Efficiency (left) and single count rates (right) of the RPC prototypes exposed to cosmic rays.

be related to the low rate capability of the glass electrodes and the relatively high count rate of spontaneous streamers observed.

The single count rate as a function of the bias supply was also measured (see Fig. 2). We observed a fast rise of the single rate with no evidence of any plateau. This is an indication that the single count rate was dominated by spontaneous (spurious) streamers and not by physics events. At the voltage supply corresponding to the beginning of the efficiency plateau, a single count rate of about 0.2 Hz/cm² was observed. This was four to five times larger than the single count rate observed with standard glass chambers without the honeycomb insert and operated with a standard Ar/isobutane/HFC-134a mixture 30/8/62 [16].

The dark current of the detector showed the same HV dependence of the single count rate. The contribution to the current due to leakage in the honeycomb structure is small, as the whole current observed could be accounted for by the single count rate and the observed charge in the pulses.

3.2 Pulse shape and charge

Clean single pulses were observed in the test RPCs with honeycomb inserts (see Fig. 3), with high pulse heights of typically 300 mV on the 25 Ω load resistance. The fraction of the signals with multi-pulse is observed through an oscilloscope to be less than 10% for isobutane fractions larger than 4%. This

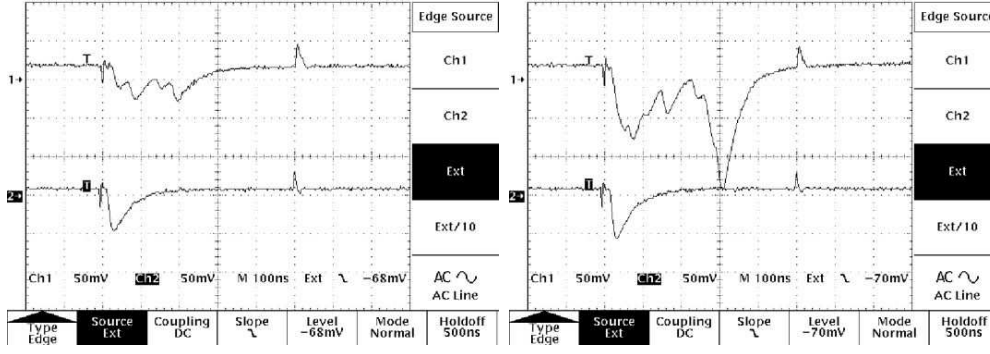


Fig. 3. Two examples of pulses (left and right frames) for Ar/isobutane mixture 95/5 at 6.5 kV in RPCs without (top trace) and with (bottom trace) the honeycomb insert upon an external trigger given by a pair of scintillator counters. The signal was terminated on a 25Ω resistance and an attenuation of 12 dB was applied.

is at full variance with the behaviour of a standard (no honeycomb) RPC operated under the same conditions (see Fig. 3), where multiple pulses were in general observed. This testifies of the effectiveness of the honeycomb structure in keeping the streamer localised within one single cell and in realising the streamer quenching. On the other hand, the absence of a fluorocarbon gas made the quenching inefficient in the standard chamber.

These qualitative indications are confirmed by the results shown in Fig. 4, where the charge distributions observed in the honeycomb RPC prototypes and in the standard RPC detector, both operated at the plateau HV with a Ar/isobutane 95/5 gas mixture, are compared. The charge distribution for the honeycomb RPC shows a major first peak with a small tail of large pulses. A probability of multi-pulse signals of about 7% can be estimated from the total area of the spectrum above the pedestal and the area of a Gaussian distribution of about 700 pC mean charge and 140 pC RMS describing the single pulse peak. The standard RPC, on the contrary, shows an indication of the single pulse peak at around 500 pC and a long tail up to very high signal charges corresponding to multi-pulse events. The multi-pulse probability is about 70% with almost half of the pulses saturating the ADC upper edge at 2.2 nC. Due to the inefficiency of the quenching process, the standard RPC also showed a detection efficiency lower than the honeycomb RPC.

The HV dependence of the charge distribution measured showed almost the same shape for the honeycomb structure, with only a small increase in the multi-pulse probability at the higher voltages. The peak charge induced on the readout pad versus the high voltage for each gas mixture is shown in Fig. 5. The charge exhibits an approximately linear dependence on the operating HV, distinctive of space charge dominated avalanche growth. The induced charge is only mildly dependent on the isobutane fraction, but always rather large as compared to a typical charge of about 100 pC of the streamer mode

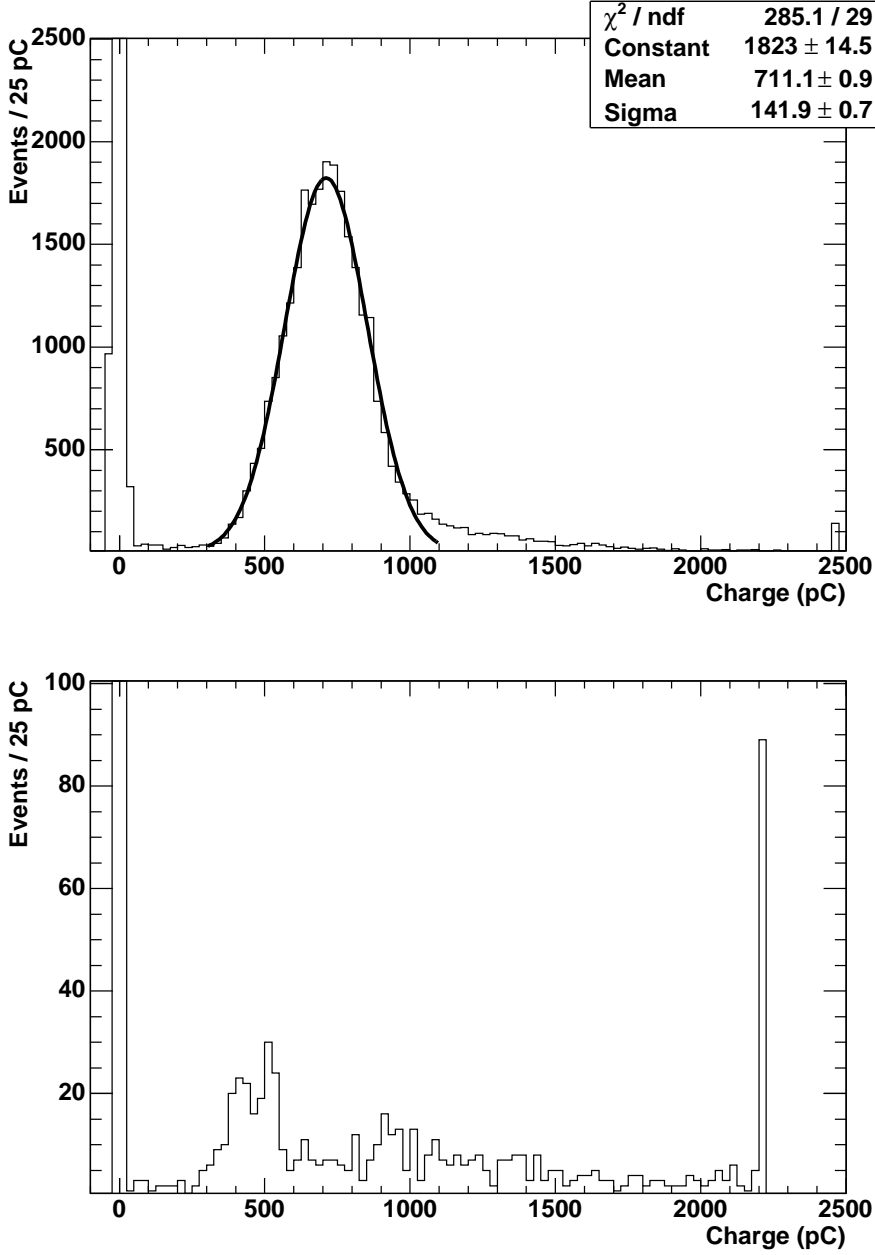


Fig. 4. Charge distributions at the plateau HV of 6.5 kV with Ar/isobutane 95/5 mixture for the honeycomb RPC (top) and a standard RPC (bottom).

operation with freon gas. This is explained qualitatively by the fact that the absence of a gas with high electron affinity such as freon leads to a higher gas gain.

The streamer charge is expected to increase with the cell dimensions. A preliminary indication of this effect was obtained with a test RPC detector assembled with a honeycomb sheet modified to obtain larger elementary cells. The charge dependence on the cell size needs to be further investigated and systematic

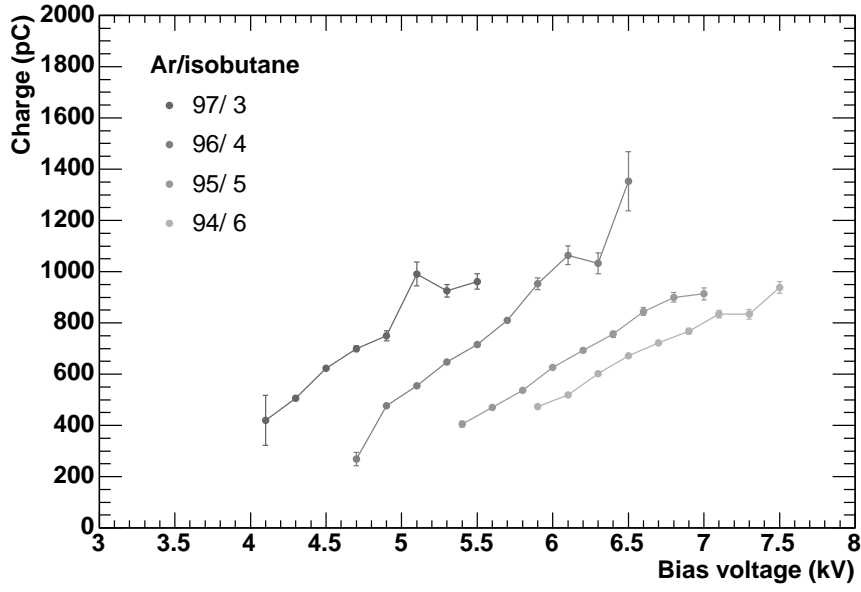


Fig. 5. Peak charge as a function of the supplied high voltage for different gas mixtures.

measurements with honeycomb sheets of different cell sizes are being planned.

3.3 Time information

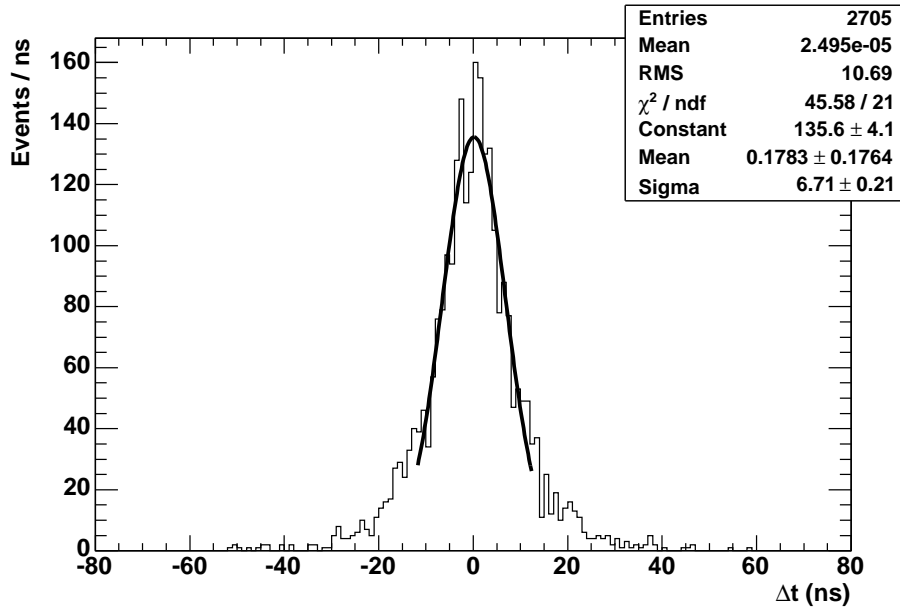


Fig. 6. Time difference in the response of two test RPCs operated at 6.5 kV with an Ar/isobutane 95/5 mixture.

A preliminary measurement of the time resolution of the test RPCs can be seen in Fig. 6, where the distribution of the time difference between two chambers, operated at 6.5 kV with an Ar/isobutane 95/5 gas mixture, is plotted. Assuming that the resolution of the two chambers was identical, a RMS of about 7.5 ns for each chamber could be estimated. Part of the large RMS can be ascribed to the non-Gaussian tails of the distribution. If a Gaussian fit to the core of the distribution is performed, a resolution of 5 ns is obtained. This resolution only slightly improved at higher voltages.

4 Summary and outlook

A few prototypes of “Mechanically Quenched” glass RPCs were built and tested. In these detectors, the quenching and transverse confinement of the streamer was obtained by means of a honeycomb structure inserted between the two resistive electrodes. We have shown that this detector design allowed stable operation in streamer mode with Ar/isobutane non-flammable gas mixtures. The optimal performance was achieved for isobutane fractions around 5%. This represents a new and promising approach to operate RPC detectors with gas mixtures not containing freon, which is recognised as the main source of RPC instability in the long term.

The preliminary results reported in this paper are encouraging, although the chambers did show a somewhat larger inefficiency than expected from geometrical considerations and the typical single count rate (0.2 Hz/cm^2) was about four times larger than in glass RPCs with standard Ar/isobutane/freon mixtures. Being essentially a new technology, many aspects require further investigation. In particular, the optimisation of the honeycomb geometry, which affects the detector efficiency and the streamer charge, and of the electrode material, which affects the rate capability and thus the efficiency of a detector with a relatively high rate of spontaneous streamers, has to be addressed. In this prospect, RPC prototypes with different cell dimensions and with bakelite electrodes are being produced. If high efficiencies can be demonstrated, a careful study of the mechanical design and of the long term behaviour of these chambers will also be deemed mandatory.

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References

- [1] R. Santonico and R. Cardarelli, Nucl. Instr. and Meth. 187 (1981) 377.
- [2] R. Cardarelli, R. Santonico, A. Di Biagio, A. Lucci, Nucl. Instr. and Meth. A 263 (1988) 20.
- [3] G. Alexander et al., “TESLA Technical Design Report. Part. IV: A Detector for TESLA”, T. Behnke, S. Bertolucci, R.D. Heuer, R. Settles editors, DESY-01-011, DESY-2001-011, DESY-01-011D, DESY-2001-011D, DESY-TESLA-2001-23, DESY-TESLA-FEL-2001-05, ECFA-2001-209;
V.Ammosov, Nucl Instr. and Meth. A 493 (2002) 355;
A.Ghezzi et al., arXiv:hep-ex/0506010, presented at the International Linear Collider Workshop 2005, Stanford, CA, 2005.
- [4] T. Francke et al., Nucl. Instr. and Meth. A 508 (2003) 83;
A. Blanco et al., Nucl. Instr. and Meth. A 508 (2003) 88.
- [5] E. Ables et al., Third International Workshop on Resistive Plate Chambers and Related Detectors, Pavia, 1996, 373.
- [6] E. Cerron Zaballo et al., Nucl. Instr. and Meth. A 392 (1997) 145.
- [7] A. Ganter et al., Nucl. Instr. and Meth. A 414 (1998) 182.
- [8] E. Cerron Zaballo et al., Nucl. Instr. and Meth. A 419 (1998) 475.
- [9] H. Sakaue et al., Nucl. Instr. and Meth. A 482 (2002) 216.
- [10] Y. Hoshi et al., Nucl. Instr. and Meth. A 508 (2003) 56.
- [11] K. Abe et al., Nucl. Instr. and Meth. A 455 (2000) 397.
- [12] F. Anulli et al., Nucl. Instr. and Meth. A 515 (2003) 322;
P. Aubert et al., Nucl. Instr. and Meth. A 479 (2002) 1.
- [13] K. Abe et al., IEEE Trans. Nucl. Sci. NS-46 (1999) 2017;
A. Abashian et al., Nucl. Instr. and Meth. A 449 (2000) 112. 342.
- [14] R. Santonico, Nucl. Instr. and Meth. A 533 (2004) 1.
- [15] H. Sakai et al., Nucl. Instr. and Meth. A 484 (2002) 153;
T. Kubo et al., Nucl. Instr. and Meth. A 508 (2003) 50.
- [16] A. Calcaterra et al., presented at the IEEE Nuclear Science Symposium 2004, Rome, I (paper N29-3), published in the Conf. Record;
A. Calcaterra et al., presented at the IEEE Nuclear Science Symposium 2005, Puerto Rico (paper N31-1), published in the Conf. Record.